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Weightbearing Computed Tomography vs Conventional Tomography for Examination of Varying Degrees of Lisfranc Injures: A Systematic Review of the Literature

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Abstract

Background: Lisfranc injuries, if not accurately diagnosed, can result in chronic pain and instability. Previous studies have examined ultrasonographs, radiographs, magnetic resonance imaging (MRI), and conventional computed tomography (CT) scan to differentiate Lisfranc instability, but they focused on a healthy/injured scale without differentiating subtle injury. Weightbearing CT (WBCT) has emerged as a diagnostic tool for detecting subtle Lisfranc injuries. This systematic review aimed to compare WBCT with conventional CT in diagnosing Lisfranc injury, and the ability to differentiate injuries of varying severities.

Methods: The review encompassed PubMed, CINAHL, MEDLINE, SPORTDiscus, and Web of Science databases from inception until July 5, 2023. Inclusion criteria involved studies on CT and/or WBCT for Lisfranc injuries and nonoperative studies. Exclusion criteria composed case reports, commentaries, postoperative imaging studies, pediatric patients, studies with nonobjective radiographic measurements, studies exclusively focused on injury classification, and studies with fewer than 5 patients because of poor statistical power. Data extraction focused on radiographic measurements of the Lisfranc complex, categorized into conventional CT, partial WBCT, and total WBCT.

Results: Out of the initially retrieved 489 articles, 9 met the inclusion criteria. Several studies consistently demonstrate that WBCT provides a higher level of accuracy in measuring the Lisfranc area, offering enhanced sensitivity to detect subtle alterations in joint structure. Moreover, WBCT exhibits superior sensitivity in distinguishing between healthy Lisfranc joints and those with injuries, particularly when identifying dorsal ligament damage. This imaging modality allows for the detection of significant variations in critical measurements like first-second metatarsal (M1-M2) distance, first cuneiform (C1)-M2 distance, and joint volumes, enabling a more comprehensive assessment of Lisfranc joint health especially with subtle instability.

Conclusion: This review evaluates the extant literature on WBCT's utility in diagnosing Lisfranc injuries and compares its effectiveness to CT in distinguishing between injuries of varying severity. WBCT, with reliable measurement techniques, appears more adept at detecting subtle Lisfranc instability compared to CT, likely by allowing the assessment of injury under load.

Keywords: Lisfranc, weightbearing computed topography, midfoot imaging, systematic review, subtle Lisfranc injury

Introduction

Injury to the Lisfranc (LF) complex poses significant challenges in diagnosis because of low diagnostic sensitivity, particularly in cases of subtle instability.[6,9,13] The identification of subtle instability within the Lisfranc joint can be difficult and lacks a consistent and reliable method to assess 3-dimensionally.[15] Although previous studies have described subtle injury as a 2- to 5-mm diastasis on plain radiographs,[6] the range of measurement is simply too large to accurately describe a subtle injury. Furthermore, although magnetic resonance imaging (MRI) and computed tomography (CT) are commonly used imaging techniques to confirm Lisfranc diagnoses, these imaging modalities have limitations in their ability to distinguish subtle LF injury.[23,24] MRI, although effective in identifying ligamentous injuries, lacks detailed bone information and is not performed under physiological load, which limits its ability to detect instability.[14] CT scans provide excellent bony detail but may miss unstable conditions when performed in nonweightbearing conditions.[13]

Weightbearing computed tomography (WBCT) has recently gained recognition as an effective imaging technique for assessing various 3-dimensional (3D) foot and ankle conditions.[2-4] This innovative diagnostic method takes advantage of load-bearing conditions and the superior bony visualization provided by CT scans to detect even subtle joint instability that might go unnoticed by traditional nonweightbearing imaging methods.[17] Previous reviews have described benefits of various imaging methods to assess Lisfranc conditions but were unable to include WBCT studies because of the recency of the publication date of many of these studies.[21] Additionally, previous reviews compared imaging modalities from a purely classification-based subjective perspective.[21] Although previous reviews have provided valuable context into how various imaging methods distinguish healthy from confirmed LF instability, the purpose of our systematic review is to expand on these findings by including WBCT and objective image–based method comparison studies that can differentiate not only between healthy and injured cases but also help assess the severity of the injury through imaging diastasis assessment.

Methods

Study Creation

This study is a systematic review conducted in accordance with the latest Preferred Reporting Items for Systematic Reviews and Meta-Analyses (PRISMA) guidelines.[12] The initial search was conducted using PubMed, CINAHL, MEDLINE, SPORTDiscus, and Web of Science from database inception until July 5, 2023. Search algorithm used in all 5 databases was (“computed tomography” OR “computerized tomography” OR “weight-bearing computed tomography” OR “weightbearing computed tomography” OR “weightbearing CT”) AND (Lisfranc OR tarsometatarsal OR “tarsal-metatarsal”). This systematic review was not publicly registered before study completion.

Inclusion and Exclusion Criteria

Inclusion criteria was studies examining CT and/or WBCT for LF injuries, nonoperative studies, full-text articles, and articles in English. Exclusion criteria included case reports, commentaries, postoperative imaging studies, pediatric patients (>18 years old), studies with fewer than 5 patients because of poor statistical power, unpublished data, studies with nonobjective radiographic measurements, and studies only focusing on classification of injury.

Study Definitions

For the purposes of this study, conventional CT refers to CT imaging that is performed in a nonweightbearing (NWB) condition. WBCT refers to CT imaging that is performed with the patient in full weightbearing.

Article Screening Process

This systematic review utilized Rayyan, an online software used for the systematic review process attested in the literature.[11] All articles that were retrieved on initial search included the search algorithm in any part of the article. Articles were first screened for duplicates with manual removal. Then, articles were screened by abstract and title followed by full-text screening for article inclusion. Finally, reference screening of included articles was performed to include additional missed studies. Article screening was completed by 1 author.

Data Extraction

Data extraction was completed by 1 author. Data extracted included first author, year of publication, healthy or injured patient demographics (age, number of feet, number of patients), description of LF injury, type of imaging used (WBCT or conventional CT), and measurements and relevant *P* values pertinent to examining WBCT vs conventional CT for LF injuries.

Article Quality Grading

Articles were graded for quality via the Methodological Index for Non-Randomized Studies (MINORS) scale.[18]

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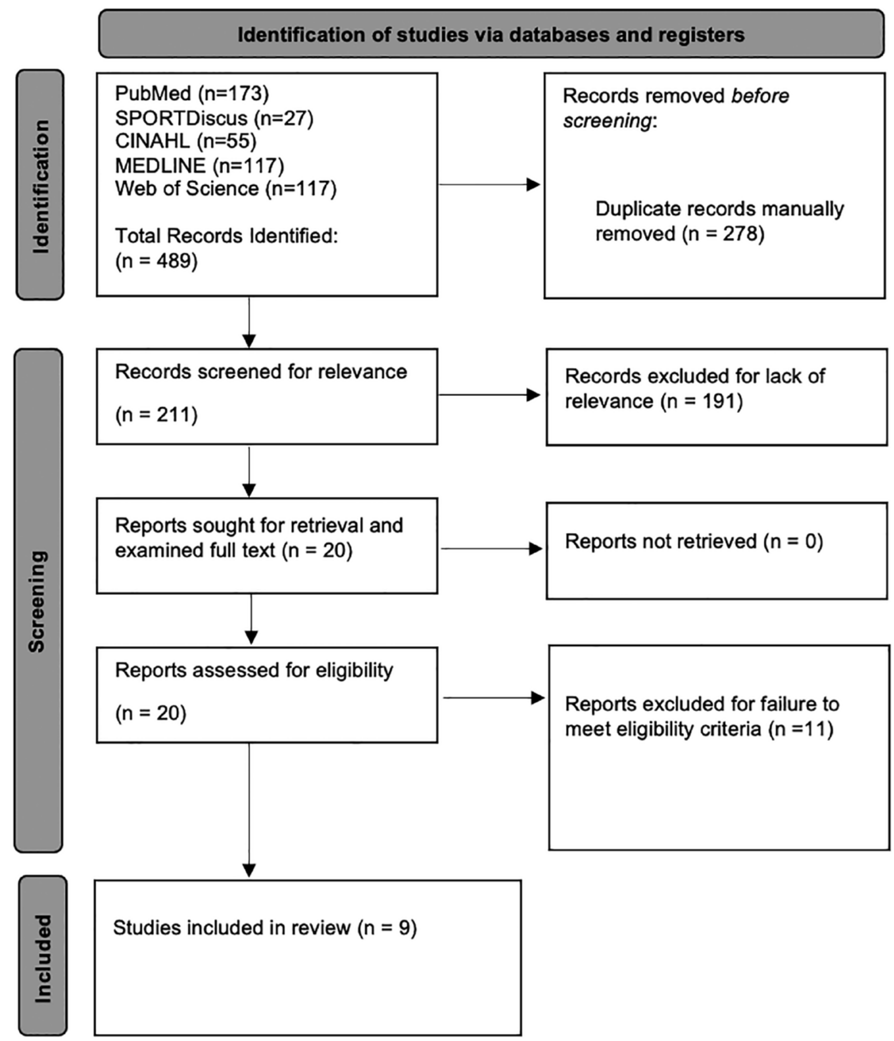

Figure 1. The Preferred Reporting Items for Systematic Reviews and Meta-Analyses (PRISMA) diagram for this systematic review depicting initial search to final article inclusion.

Noncomparative articles were graded on a 0 to 16 scale and comparative studies on a 0 to 24 scale, with each item being worth 0 to 2 points.[18]

Statistical Analysis

This study used the Statistical Package for the Social Sciences (SPSS), version 29.0 (Armonk, NY: IBM Corp) for statistical analysis. Frequency-weighted means were used to synthesize data from individual articles without statistical analysis calculation. A narrative approach to systematic review was undertaken for this study because of heterogeneity of data as no meta-analysis could be performed. In order to maintain significant figures during report, any value less than .1 was rounded to .1 for clarity. All *P* values were recorded in their original significant figures to not skew the significance data.

Results

Initial Search Results and Quality Grading

A total of 9 articles met the inclusion criteria from a total of 489 articles retrieved during the initial search process (Figure 1).[1,5,7,13,16,19,20,22,25] All articles were graded according to the MINORS scale for quality (Table 1).[18] The mean MINORS score for the 9 included articles was 12.4 ± 3.4 (range: 8.0-16.0).[1,5,7,13,16,19,20,22,25] Six articles were retrospective observational studies, and 3 articles were cadaveric studies.

Table 1. The Methodological Index for Non-Randomized Studies (MINORS) scale for quality grading of the included studies in this systematic review.

First Author (Year)	Study Type	Total MINORS Score	Clearly Stated Aim	Inclusion of Consecutive Patients	Prospective Collection of Data	End points Appropriate to Study Aim	Unbiased Assessment of Study End Point	Follow-up Period Appropriate to Study Aim	<5% Lost to Follow-up	Prospective Calculation of the Study Size	Adequate Control Group	Contemporary Groups	Baseline Equivalence of Groups	Adequate Statistical Analysis
Wijetunga[25] (2023)	Noncomparative	8	2	2	0	2	2	0	0	0	–	–	–	–
Sripanich[22] (2021)	Noncomparative	8	2	2	0	2	2	0	0	0	–	–	–	–
Sripanich[20,21] (2020)	Comparative	14	2	0	0	2	2	0	0	0	2	2	2	2
Sripanich[19] (2020)	Comparative	14	2	0	0	2	2	0	0	0	2	2	2	2
Shim[16] (2022)	Comparative	15	2	2	0	2	2	0	0	0	2	2	1	2
Penev[13] (2021)	Comparative	14	2	0	0	2	2	0	0	0	2	2	2	2
Falcon[7] (2023)	Comparative	15	2	2	0	2	2	0	0	0	2	2	1	2
Essa[5] (2022)	Noncomparative	8	2	2	0	2	2	0	0	0	–	–	–	–
Bhimani[1] (2021)	Comparative	16	2	2	0	2	2	0	0	0	2	2	2	2

Patient Demographics

Patients were divided into healthy cohort (patient or cadaver) as compared to the LF cohort (patient or cadaver). Some articles included healthy cohorts as well as contralateral healthy feet controls in the LF cohort. The healthy patient cohort (n=308 patients; n=440 feet) had a frequency-weighed mean age of 41.5 ± 6.9 years (100.0% reported). One article did not report the number of patients for the healthy patient cohort (n=96 feet) with an average age of 38.0 years.[7] The healthy cadaver cohort (n=32 patients; n=64 feet) and the LF cadaver cohort (n=32 patients; n=64 feet) had a frequency-weighted mean age at death of 54.3 ± 12.8 years (100.0% reported). The LF cohort (n=88 patients; n=88 Lisfranc feet; n=44 healthy contralateral feet) had a frequency-weighted mean age of 37.7 ± 3.8 years (100.0% reported). One article did not report the number of patients for the LF cohort (n=15 feet) with an average age of 39.5 years.[7] Refer to Table 2 for article, patient demographic information, and outcome measurements.

Weightbearing vs Conventional CT

Wijetunga et al[25] found that healthy Lisfranc area measurement increased from 87.0 ± 21.0 mm^2 in NWB CT to 90.0 ± 21.0 mm^2 via WBCT with high intraobserver (0.998) and interobserver agreement (0.964). The same study found that the area difference (WB area – NWB area) was 1.0 ± 1.9 mm^2 and the area ratio (WB area divided by NWB area) was 1.0 ± 0.1 mm^2 for the healthy cohort (n=91 patients; n=91 feet) via CT.[25] This study demonstrates that the Lisfranc complex experiences changes in morphology under weightbearing, indicating that studying the Lisfranc pathology under weightbearing may reveal widening not detected on conventional CT.

Cadaveric Data

Three cadaveric studies met our inclusion criteria, and each study compared conventional CT to WBCT. Sripanich et al[20] assessed Lisfranc instability for 7 different test groups of increasing Lisfranc ligamentous injury by measuring the axial and coronal first cuneiform (C1) to second metatarsal (M2) in CT, partial WBCT, and WBCT. For 5 of 7 groups, all 3 image modalities detected significant differences between injured and healthy ($P < .05$).[20] However, when only injury to the dorsal Lisfranc ligament was present, both measurements detected significant differences from healthy using partial WBCT or total WBCT. For axial C1-M2, WBCT found significant differences between healthy measurements for CT and WBCT ($P = .042$).[20]

Another cadaveric study by Penev et al[13] compared CT and WBCT to detect injury in various levels of Lisfranc instability severity. When comparing C1-M2 distances, conventional CT was only able to significantly detect Lisfranc injury in the most severe test group, whereas WBCT was able to detect significant differences between healthy and injured for 2 of the 3 groups.[13] When only injury to the dorsal Lisfranc was present, WBCT failed to detect injury ($P = .404$). For the 2 remaining measurements that provided statistical comparison between CT and WBCT (dorsal displacement and first to second metatarsal [M1-M2] distance), both modalities were capable of detecting injury to the same sensitivity ($P < .05$).[13]

In a final cadaveric study, asymmetric lambda measurements (+ if C1-M2 > M1-M2, C1-C2) were used to assess instability in groups of increasing Lisfranc ligamentous injury.[19] Conventional CT, partial WBCT, and total WBCT scans were used for each specimen, and the percentage of positive lambda followed the trend of CT < partial WBCT < WBCT for each group.[19] For complete Lisfranc injury (injury to dorsal, interosseous, and plantar Lisfranc ligaments), CT demonstrated 33.3% positive lambda, whereas WBCT demonstrated 83.3% positive lambda.[19]

WBCT Only

Bhimani et al[1] found many measurements of the Lisfranc joint to be greater in the Lisfranc injured group as compared to uninjured healthy feet via WBCT including coronal Lisfranc joint volume ($P < .001$), axial LF joint volume ($P < .001$), axial LF joint area ($P < .001$), C1-C2 area ($P = .001$), C1-M2 distance ($P < .001$), C1-C2 distance ($P < .001$), M1-M2 distance ($P = .002$), first and second tarsometatarsal (TMT) alignment ($P < .001$), first TMT dorsal step-off ($P = .008$), and second TMT dorsal step-off ($P = .001$).

Sripanich et al[22] examined 2 different methods for WBCT measurement and found distances of 3.9 ± 0.5 mm and 4.2 ± 0.5 mm for axial C1-M2 distance for healthy patients (n=96 patients; n=96 feet). Similarly, 2 different methods of WBCT measurement found distances of 3.8 ± 0.4 mm and 4.0 ± 0.5 mm for coronal C1-M2 distance for healthy patients (n=96 patients; n=96 feet). Intraobserver and interobserver reliability was moderately high for all measurements (range: 0.645-0.84).[22] One method involved measuring from a reference point a specific distance along the M2 base and the second method relying on nearby bony landmarks. In terms of intraobserver evaluation, I-Ax exhibited a high level of agreement ($R = 0.802$), whereas interobserver evaluation showed good agreement ($R = 0.727$).[22] For I-Cor, there was excellent agreement in both interobserver ($R = 0.814$) and intraobserver ($R = 0.840$) evaluations. Both II-Ax and II-Cor demonstrated good agreement for both intraobserver ($R = 0.730$, $R = 0.708$) and interobserver ($R = 0.705$, $R = 0.645$) assessments.[22]

Table 2. Patient cohort and measurement methodololgy for each included study.

	Healthy Cohort			Lisfranc Cohort					
Author	Patients	Feet	Age (SD or Range)	Patients	Feet	Age (SD or Range)	Desription of Injury	Measurements	Notes / *P* Values
Wijetunga[25] (2023)	91	91	32.6 (12.6)	–	–	–	–	Bilateral WBCT (WB and NWB)	
								1. LF NWB area measurement (mm^2)	
								2. LF WB area measurement (mm^2)	
								3. Area difference (WB area – NWB area)	
								4. Area ratio (WB area / NWB area)	
Sripanich[22] (2021)	96	96	46 (16.1.)	–	–	–	–	WBCT	
								1. Method 1: Axial C1-M2 distance (mm)	–
								2. Method 1: Coronal C1-M2 distance (mm)	–
								3. Method 2: Axial C1-M2 distance (mm)	–
								4. Method 2: Coronal C1-M2 distance (mm)	–
Sripanich[20] (2020)	12 (C)	24 (C)	48 (15.2)	12 (C)	24 (C)	48 (15.2)	Divided into 4 groups, then randomly grouped for 3 additional procedures	CT scans (NWB, PWB, WB)	
							1. Healthy	1. Axial C1-M2 distance (mm)	
							2. Dorsal LF ligament (DLL)	Healthy	Significant difference between NWB and WB ($P = .041$)
							3. Interosseous Lisfranc ligament (ILL)	Group 2	Significant difference from healthy for PWB and WB ($P < .05$)
							4. Plantar Lisfranc ligament (PLL)	Group 3	Significant difference from healthy for NWB, PWB, and WB ($P < .05$)
							5a. Capsule of the first tarsometatarsal joint (1TMT)	Group 4	Significant difference from healthy for NWB, PWB, and WB ($P < .001$)
							5b. Capsule of the second tarsometatarsal joint (2TMT)	Group 5a	Significant difference from healthy for NWB, PWB, and WB ($P < .001$)
							5c. Medial-middle intercuneiform ligament (ICL)	Group 5b	Significant difference from healthy for NWB, PWB, and WB ($P < .001$)
							6ab, 6ba. Capsule of first TMT, capsule of second TMT	Group 5c	Significant difference from healthy for NWB, PWB, and WB ($P < .001$)
							6bc, 6cb. Capsule of second TMT, ICL	Group 6ab	Significant difference from healthy for NWB, PWB, and WB ($P < .001$)
							6ac, 6ca. Capsule of first TMT, ICL	Group 6ac	Significant difference from healthy for NWB, PWB, and WB ($P < .001$)
								Group 6bc	Significant difference from healthy for NWB, PWB, and WB ($P < .001$)
								Group 7	Significant difference from healthy for NWB, PWB, and WB ($P < .001$)
								1. Coronal C1-M2 distance (mm)	
								Healthy	
								Group 2	Significant difference from healthy for PWB and WB ($P < .05$)
								Group 3	Significant difference from healthy for NWB, PWB, and WB ($P < .05$)

(continued)

Table 2. (Continued)

Author	Healthy Cohort Patients	Healthy Cohort Feet	Healthy Cohort Age (SD or Range)	Lisfranc Cohort Patients	Lisfranc Cohort Feet	Lisfranc Cohort Age (SD or Range)	Desription of Injury	Measurements	Notes / *P* Values
								Group 4	Significant difference from healthy for NWB, PWB, and WB ($P < .001$)
								Group 5a	Significant difference from healthy for NWB, PWB, and WB ($P < .001$)
								Group 5b	Significant difference from healthy for NWB, PWB, and WB ($P < .001$)
								Group 5c	Significant difference from healthy for NWB, PWB, and WB ($P < .001$)
								Group 6ab	Significant difference from healthy for NWB, PWB, and WB ($P < .001$)
								Group 6ac	Significant difference from healthy for NWB, PWB, and WB ($P < .001$)
								Group 6bc	Significant difference from healthy for NWB, PWB, and WB ($P < .001$)
								Group 7	Significant difference from healthy for NWB, PWB, and WB ($P < .001$)
Sripanich[19] (2020)	12 (C)	24 (C)	46 (14.8)	12 (C)	24 (C)	46 (14.8)	4 groups	CT scans (NWB, partial WB, WB)	
							1. Healthy/intact LF ligaments	1. Asymmetric lambda sign (+ if C1-M2 > M1-M2, C1-C2)	
							2. Dissected dorsal LF ligament	Healthy	–
							3. Dissected dorsal and interosseous Lisfranc ligaments	Dissected dorsal LF ligament	–
							4. Dissected dorsal, interosseous, and plantar ligaments	Dissected dorsal and interosseous LF ligaments	–
Shim[16] (2022)	85	85	48.5 (16.5)	30	60—healthy contralateral	34.9 (10.9)	2 groups	CT Scans (NWB only)	
							Group A: Treated surgically (n = 24, 80%)	1. Coronal: Longest C1-M2 distance (mm) top	No significant difference between injured groups ($P = .104$)
							Group B: Treated conservatively, diastasis <1 mm (n =6, 20%)	Healthy	
								Group B: Conservative	Significant contralateral difference ($P = .026$)
								Group A: Surgical	Significant contralateral difference ($P < .001$)
								2. Coronal: Longest C1-M2 distance (mm) middle	Significant difference between injured groups ($P = .038$)
								Healthy	
								Group B: Conservative	No significant difference ($P = .394$)
								Group A: Surgical	Significant contralateral difference ($P < .001$)
								3. Coronal: Longest C1-M2 distance (mm) base	Significant difference between injured groups ($P = .001$)
								Healthy	
								Group B: Conservative	No significant contralateral difference ($P = .818$)
								Group A: Surgical	Significant contralateral difference ($P < .001$)

(continued)

Table 2. (Continued)

	Healthy Cohort			Lisfranc Cohort					
Author	Patients	Feet	Age (SD or Range)	Patients	Feet	Age (SD or Range)	Desription of Injury	Measurements	Notes / *P* Values
Penev[13] (2021)	8 (C)	16 (C)	76 (11)	8 (C)	16 (C)	76 (11)	3 Groups	CT Scans (NWB/resting and WB)	
							Cut 1: cutting dorsal and interosseous LF ligaments	1. C1-M2 distance (mm)	**All compared to healthy
							Cut 2: cutting ligament between C1 and M3	Healthy	
							Cut 3: Cutting plantar ligament	Cut 1: Dorsal and interosseous ligaments	WB: $P = .404$
								Cut 2: Dorsal, interosseous, and C1-M3 ligaments	WB: $P = .001$
								Cut 3: Dorsal, interosseous, plantar, and C1-M3 ligaments	NWB and WB: $P = .001$
								2. M1-M2 distance (mm)	
								Cut 1: Dorsal and interosseous ligaments	–
								Cut 2: Dorsal, interosseous, and C1-M3 ligaments	NWB: $P = .013$, WB: $P = .001$
								Cut 3: Dorsla, interosseous, plantar, and C1-M3 ligaments	NWB: $P = .004$, WB: $P = .001$
								3. Meary angle (degrees)	
								Healthy	-
								Cut 1: Dorsal and interosseous ligaments	-
								Cut 2: Dorsal, interosseous, and C1-M3 ligaments	-
								Cut 3: Dorsal, interosseous, plantar, and C1-M3 ligaments	-
								4. Dorsal displacement M2 (mm)	
								Healthy	-
								Cut 1: Dorsal and interosseous ligaments	-
								Cut 2: Dorsal, interosseous, and C1-M3 ligaments	–
								Cut 3: Dorsal, interosseous, plantar, and C1-M3 ligaments	NWB: $P = .047$, WB: $P = .023$
Falcon[7] (2023)	–	96	38.02 (17.23)	–	15	39.53 (24.3)		WBCT	
								1. M1-M2 distance (mm)	
								Healthy	
								Injured	Significantly greater ($P < .0001$)
								2. C1-M2 distance (mm)	
								Healthy	
								Injured	Signicantly greater ($P < .0001$)
								3. C1-C2 distance (mm)	
								Healthy	
								Injured	similar ($P = .6186$)
								4. Sagittal descent (mm)	
								Healthy	
								Injured	Similar ($P = .1916$)

(continued)

Table 2. (Continued)

	Healthy Cohort			Lisfranc Cohort					
Author	Patients	Feet	Age (SD or Range)	Patients	Feet	Age (SD or Range)	Desription of Injury	Measurements	Notes / *P* Values
Essa[5] (2022)	-	-	-	44	44	41.4 (23-58)		NWB CT (described as 3D CT)	
								1. Sensitivity	
								First metatarsal subluxation	
								Second metatarsal subluxation	
								Third metatarsal subluxation	
								Fourth metatarsal subluxation	
								Fifth metatarsal subluxation	
								2. Specificity	
								First metatarsal subluxation	
								Second metatarsal subluxation	
								Third metatarsal subluxation	
								Fourth metatarsal subluxation	
								Fifth metatarsal subluxation	
								3. Negative predictive value	
								First metatarsal subluxation	
								Second metatarsal subluxation	
								Third metatarsal subluxation	
								Fourth metatarsal subluxation	
								Fifth metatarsal subluxation	
								4. Positive predictive value	
								First metatarsal subluxation	
								Second metatarsal subluxation	
								Third metatarsal subluxation	
								Fourth metatarsal subluxation	
								Fifth metatarsal subluxation	
								5. Area under the ROC	
								First metatarsal subluxation	
								Second metatarsal subluxation	
								Third metatarsal subluxation	
								Fourth metatarsal subluxation	
								Fifth metatarsal subluxation	
Bhimani[1] (2021)	36	72	35.7 (16.5)	14	28 (contralateral comparison)	32.2 (15.5)	Intraoperatively confirmed LF injury (ruptured dorsal ligament)	WBCT (bilateral)	
								1. Coronal LF joint volume (mm^3)	
								Patient group: Injured	Significantly larger ($P < .001$)
								Patient group: Uninjured	
								2. Axial LF joint volume (mm^3)	
								Patient group: Injured	Significantly larger ($P < .001$)
								Patient group: Uninjured	
								3. Axial LF joint area (mm^2)	
								Patient group: Injured	Significantly larger ($P < .001$)
								Patient group: Uninjured	

(continued)

Table 2. (Continued)

	Healthy Cohort			Lisfranc Cohort					
Author	Patients	Feet	Age (SD or Range)	Patients	Feet	Age (SD or Range)	Desription of Injury	Measurements	Notes / *P* Values
								4. C1-C2 area (mm^2)	
								Patient group: Injured	Significantly larger ($P = .001$)
								Patient group: Uninjured	
								5. C1-M2 distance (mm)	
								Patient group: Injured	Significantly larger ($P < .001$)
								Patient group: Uninjured	
								6. C1-C2 distance (mm)	
								Patient group: Injured	Significantly larger ($P < .001$)
								Patient group: Uninjured	
								7. M1-M2 distance (mm)	
								Patient group: Injured	Significantly larger ($P = .002$)
								Patient group: Uninjured	
								8. First TMT alignment (mm)	
								Patient group: Injured	Significantly larger ($P < .001$)
								Patient group: Uninjured	
								9. Second TMT alignment (mm)	
								Patient group: Injured	Significantly larger ($P < .001$)
								Patient group: Uninjured	
								10. First TMT dorsal step-off (mm)	
								Patient group: Injured	Significantly larger ($P = .008$)
								Patient group: Uninjured	
								11. Second TMT dorsal step-off (mm)	
								Patient group: Injured	Significantly larger ($P = .001$)
								Patient group: Uninjured	

Abbreviations: CI/C2, first/second cuneiform; CT, computed tomography; LF, Lisfranc; M1/M2/M3, first/second/third metatarsal; NWB, nonweightbearing; PWB, partial weightbearing; ROC, receiver operating characteristic; TMT, tarsometatarsal; WB, weightbearing; WBCT, weightbearing computed tomography.

Table 3. Summary of results. Studies were broken into weightbearing versus convential computed topography (CT), cadaveric, weightbearing CT, and conventional CT categories.

Study and Year	Findings
Weightbearing vs conventional computed tomography	Lisfranc area increased with WBCT, with high intraobserver (0.998) and interobserver (0.964) agreement. Area difference (WB area – NWB area) was 1.0 ± 1.9 mm^2, and area ratio was 1.0 ± 0.1 mm^2 for the healthy cohort via CT
Cadaveric studies	Sripanich et al[19-21] (2020): Detected significant differences between injured and healthy in 5 of 7 groups using CT, partial WBCT, and WBCT. Penev et al[13] (2021): WBCT detected significant differences between healthy and injured for 2 of 3 groups. For dorsal Lisfranc injury, WBCT failed to detect injury. Lambda measurements demonstrated better detection with WBCT.
WBCT only	Bhimani et al[1] (2021): Various Lisfranc joint measurements were greater in the injured group compared with healthy feet via WBCT. Sripanich et al[22] (2021): WBCT measurements showed good intraobserver and interobserver reliability. Falcon et al[7] (2023): WBCT revealed greater M1-M2 distance in injured feet and significant differences in C1-M2 distance.
Conventional CT only	Essa et al[5] (2022): Sensitivity, specificity, NPV, PPV, and ROC values varied for metatarsal subluxation, with the second metatarsal having the highest sensitivity. Shim et al[16] (2022): Conventional CT showed differences in C1-M2 distance for surgical and conservative groups, with contralateral comparisons and side-to-side differences (STSD) aiding in differentiation.

Abbreviations: C1/C2, first/second cuneiform; CT, computed tomography; M1/M2, first/second metatarsal; NPV, negative predictive value; NWB, nonweightbearing; PPV, positive predictive value; ROC, receiver operating characteristic; WB, weightbearing; WBCT, weightbearing computed tomography.

Falcon et al[7] used WBCT to examine healthy feet (n = 15) as well as feet with confirmed Lisfranc injuries (n = 96) and found a significantly greater M1-M2 distance in injured feet as compared to controls (3.3 ± 0.9 mm vs 2.75 ± 0.7 mm; $P < .0001$). The same study found greater C1-M2 distance in injured than healthy feet ($P < .0001$), but found no significant difference in C1-second cuneiform (C2) distance ($P = .6186$) or sagittal descent ($P = .1916$).[7]

Conventional CT Only

Essa et al[5] examined the sensitivity, specificity, negative predictive value (NPV), positive predictive value (PPV), and area under receiver operating characteristic (ROC) curve of 3-dimensional evaluation of Lifranc injury. Each metric was found for first-fifth metatarsal subluxation. Sensitivity measurements ranged from 31.4 to 69.5, with second metatarsal subluxation having the highest sensitivity. Specificity ranged from 29.3 to 74.1, with fifth metatarsal subluxation having the highest specificity.[5] Negative and positive predictive values ranged from 19.9 to 69.5 and 36.1 to 79.8, respectively, with the fifth metatarsal subluxation having the highest NPV and second metatarsal subluxation having the highest PPV.[5] For ROC, the values ranged from 0.52 to 0.56, with first metatarsal subluxation having the highest value.[5]

Shim et al[16] assessed the Lisfranc complex by comparing treatment decision (conservative vs surgical) to a retrospective CT-based decision. In this study, coronal measurements of the C1-M2 distance were manually performed at the top, middle, and base of the medial cuneiform.[16] Although the middle and base measurements were able to differentiate the surgical and conservative groups (middle, $P = .038$; base = 0.001) the top C1-M2 measurement demonstrated no difference ($P = .104$).[16] Additionally, contralateral comparison was performed for both groups. For the surgical group, significant differences were found between the injured and uninjured side for all 3 measurements ($P < .001$).[16] However, for the conservatively treated Lisfranc group, contralateral comparison only found significant differences at the C1-M2 (top) measurement ($P = .026$).[16] When assessing side-to-side differences (STSD) at all 3 measurements, conventional CT was able to differentiate groups ($P < .038$).[16] For the surgical group, STSD of greater than 1 and 2 mm was significantly associated with the surgical group ($P < .001$).[16] For a summary of results, see Table 3.

Discussion

In this systematic review, assessment of Lisfranc complex instability using traditional CT and WBCT was evaluated. Although this review includes articles that differentiate healthy and injured patient populations, many articles included compare various levels of Lisfranc injury severity with the purpose of understanding how WBCT and CT differ in terms of differentiating different levels of Lisfranc instability.

Previous reviews investigated ultrasonographs, MRIs, radiographs, and CT scans to detect Lisfranc injury but were limited on describing distinctions between different levels of Lisfranc instability.[21] As conventional CT has long been the gold standard for diagnosing subtle Lisfranc injury, previous reviews tended to compare diagnoses based on radiographs, MRIs, or ultrasonographs to those of CT scans.[21] However, as articles included in our review demonstrate, conventional CT frequently fails to diagnose subtle Lisfranc injury or may require additional measurements to confirm diagnosis.[13,16,20] Also, as only sensitivity and/or specificity of imaging modalities was statistically analyzed in previous reviews, it was of great interest to include studies with direct statistical comparison.[21] Given the recent development of WBCBT (weightbearing cone beam tomography) for the detection and distinction of subtle injuries, there is a need for providing an updated review of image-based assessments of Lisfranc injuries.[10] Although NWB CT may be preferred by patients in cases of extreme pain, WBCT may be better suited when assessing minor pain that may be the culprit of subtle Lisfranc injury as NWB may not reflect the true injury pattern. This review also aims to be the first to explore WBCT evaluation of Lisfranc injuries with varying degrees of severity.

In this review, 4 of 9 studies analyzed the Lisfranc complex using both conventional and WBCT.[13,19,20,25] Although 1 of these studies simply analyzed the Lisfranc area in NWB and WB, the remaining 3 were cadaveric studies that evaluated image modality success at detecting instability with varying degrees of severity.[25] All 3 cadaveric studies found that partial or total WBCT was significantly more successful at detecting instability at lower levels of ligamentous injury.[13,19,20] When assessing asymmetry, Sripanich et al[19] found that WBCT was able to detect a higher percentage of injury for all included levels of Lisfranc injury. As no statistical analysis was performed, these results can be only described on a purely absolute scale. In a study by Penev et al,[13] complete Lisfranc ligamentous injury (injury to dorsal, interosseous, C1-M3 ligament, and plantar ligament) was required for conventional CT to significantly detect injury, whereas WBCT detected injury without the need for plantar ligamentous injury. However, it is crucial to acknowledge that both WBCT and traditional CT demonstrated deficiencies in identifying instability in cases where only the dorsal Lisfranc ligament was injured. From a kinematic standpoint, this shortcoming from both WBCT and conventional CT is expected, as the dorsal Lisfranc ligament is the smallest by volume size and experiences the lowest biomechanical load.[8] The dorsal Lisfranc ligament is 4.5 times smaller than the interosseous ligament and 2 times smaller than the plantar ligament on average.[8] However, one measurement (axial C1-M2 distance) in a study by Sripanich et al[20] was able to detect dorsal Lisfranc instability using WBCT. This possibly indicates that shortcomings surrounding WBCT's ability to detect dorsal instability was not due to the imaging modality but more so the measurement approach. Future studies surrounding the development of a consistent, repeatable WBCT measurement approach that can detect dorsal Lisfranc ligament injury could potentially solidify WBCT as the gold standard for differentiating all types of Lisfranc injury. As CT is a 3-dimensional imaging tool, future development of normalized volumetric measurement would be of high interest over the measurements included in this present review because of being a more comprehensive assessment.

Of the included studies that analyzed only WBCT assessment of the Lisfranc complex, none were able to describe cohorts of known degrees of differing instability. Moreover, although studies like the one conducted by Bhimani et al[1] achieved successful differentiation between Lisfranc injuries and healthy individuals by employing contralateral comparison, it is important to exercise caution when comparing to internal controls. This caution arises from the fact that Lisfranc injuries tend to occur more frequently in individuals with specific anatomical indicators (such as shorter second metatarsal joint height), which might not make them the most suitable reference for the general population.[23] Furthermore, this study assumed proper treatment choice for the Lisfranc group, which may vary between physicians, possibly creating a Lisfranc patient cohort of only specific injury patterns. Future studies should compare Lisfranc-injured populations to noninternal controls, while also having an emphasis on including various degrees of Lisfranc injury. An ideal approach would be to conduct a study, similar to the one conducted by Shim et al,[16] using WBCT to compare treatment choices for various types of Lisfranc injuries to a retrospective WBCT assessment.

It is also important to note the limitations of this study. As measurement choices used across studies was not consistent, conclusions were made on summarizing each study instead of directly comparing results between studies. Future research should focus on direct comparison studies between conventional CT and WBCT in order to assess the superiority or noninferiority of either imaging modality. Despite this fact, this systematic review presents the largest study to date on the topic of WBCT for LF injuries. Another potential concern may lie in the reproducibility in WBCT scan protocol. We assumed that scans were taken with a 50/50 load distribution between feet. This could not be the case soon after LF injury with pain avoidance adaptive behavior. However, assessing WBCT protocol was not the focus of this review, but rather, how weightbearing affects LF injury detection. Therefore, any weight beyond conventional CT was considered WB and assumed to be symmetrical between feet. Additionally, access to WBCT is still limited within the United States and internationally, so reproducibility of LF assessment is still limited in a clinical setting. Furthermore, our review only found 9 articles within our inclusion criteria, thus providing a relatively small sample size. Finally, 33% of included studies were cadaveric, which may not accurately represent clinical injury patterns. However, a cadaveric model allowed for testing of numerous levels of increasing Lisfranc injury severity, thus giving a more comprehensive imaging diagnostic assessment than any other included study. Furthermore, although past studies define subtle injury as 2 to 5 mm diastasis,[6] a cadaveric model may allow for an imaging assessment of known injury that causes less diastasis and would be overlooked clinically. Revisiting this topic of WBCT assessment of LF injury, particularly differentiating between different severities of injury, would be of great interest in the future and has potential to improve patient care.

Conclusion

In summary, this review provides information from the existing literature on the use of WBCT in diagnosing LF injuries and compares its effectiveness to conventional CT in distinguishing between different LF injuries of varying severity. With proper, repeatable measurement, WBCT was able to detect small deviations in asymmetry and LF area as compared to conventional CT. WBCT was also capable of detecting Lisfranc instability in cases of subtle injury, while being able to differentiate being injury groups at lower levels of injury. Although this review was incapable of completely generalizing the finding of the included studies, it is the first review to include objective image modality comparisons as well as distinguish Lisfranc injuries of varying severities. More research is needed on this topic before the superiority of WBCT can be recommended for the detection of LF injuries.

Ethical Approval

Ethical approval was not sought for the present study because it is a systematic review.

Declaration of Conflicting Interests

The author(s) declared the following potential conflicts of interest with respect to the research, authorship, and/or publication of this article: Cesar de Cesar Netto, MD, PhD, reports payment or honoraria for lectures, presentations, speakers bureaus, manuscript writing, or educational events and stock or stock options from CurveBeam, as a paid consultant. ICMJE forms for all authors are available online.

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